University of Canterbury, School of Forestry,
Honours Thesis

THE ECONOMIC VALUE OF EUCALYPTUS BOSISTOANA FOR VENEER PEELING WITH NATURALLY DURABLE POSTS AS A BY-PRODUCT

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Abstract

Eucalyptus bosistoana is one of the breeding objectives of NZDFI (New Zealand Dryland Forest Initiatives). Currently, most of the material peeled in the New Zealand veneer market is *Pinus radiata* of which the low stiffness is an important deficiency in producing structural veneers. So, it is interesting to know the value of peeling *E. bosistoana* as it can produce much stiffer veneers with the peeler core produced into naturally durable posts as a product.

A tree data was acquired from NZDFI on a trial site by Craven Road North of Blenheim, New Zealand. A veneer price data was acquired by surveying JNL (Juken New Zealand Ltd.). Together with a table derived from literature covering the value range of the important variables the study looked into and a model on R Studio, the value of a *E. bosistoana* tree was simulated, the sensitivity analysis of the variables were conducted and a comparison of *E. bosistoana* and *P. radiata* were done.

It is concluded that the out of the variables tested in the study: stiffness profile, conversion ratio, volumetric shrinkage, veneer price, peeler core size and post regimes, the conversion ratio is the most important variable. Under base scenario in which a conversion ratio of 0.7 was applied, the value of one *E. bosistoana* tree of 29.6cm DBH is NZ$102 while a tree only worth NZ$41 at 0.25 conversion ratio. MoE profile is insignificant under the current price data as no or less price premium was assumed for stiffer veneers. Also, it is concluded that by processing a small peeler core of 30mm, by producing the peeler core into posts or by applying a price premium to stiffer veneers, the value of *E. bosistoana* exceeds *P. radiata* regardless of DBH. The result of the study can support the growers, peelers and tree breeders in making decisions about how much the tree is worth and what to breed for.

Key words: *Eucalyptus bosistoana*, *Pinus radiata*, value, veneer, LVL, stiffness, structural product, naturally durable posts

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Introduction

E. bosistoana is a stiff, naturally durable and fast-growing species which has recently gained attention by tree growers and breeders like NZDFI (New Zealand Dryland Forest Initiatives). Although *E. bosistoana* has great structural property, the timber/beams produced with it tend to bend severely, therefore the ideal potential uses are veneer for LVL and naturally durable posts (Millen et al., 2019). Currently in New Zealand, most of the veneer manufactures have to use *P. radiata* because it is available. *E. bosistoana* is almost twice as stiff as *P. radiata* which makes it a possible alternative for *P. radiata* in making veneers for stiff LVL. Under optimum conditions, *E. bosistoana* can exceed the growth rate that of *P. radiata's* (Millen et al., 2019). The species is also able to make super-stiff LVLs of over 16 GPa which is currently absent in New Zealand market because *P. radiata* cannot reach the required stiffness (Altaner et al., 2019). Furthermore, *E. bosistoana* has the potential to produce valuable naturally durable posts as a by-product. The technological development of spindle-less lathes achieved in previous years facilitate the possibility of peeling young *E. bosistoana* plantations because a much smaller non-veneer core can be made using this type of machine.

Problem statement

The low stiffness is a significant deficiency for *P. radiata* to be used for structural uses such as LVL veneer production which makes it interesting to know the value for peeling a much stiffer material like *E. bosistoana*. Because there is no existing market of *E. bosistoana* logs or veneers, it is unknown if peeling the much stiffer species is financially viable. The value of peeling the species for veneers can be modelled using input variables derived from literature which include:

- veneer conversion ratio;
- pith to bark stiffness profile;
- veneer price;
- volumetric shrinkage;
- peeling core size; and
- targeting a post regime

The sensitivity of the stem value with the different value points of the variables can be tested to identify the most important variables. This is to inform the growers of what is the maximum economically feasible growing costs by providing them an estimated market value of an *E. bosistoana* tree to make veneers. It also supports veneer peelers in deciding whether or not to purchase this species.

Research questions

1. What is a realistic range of the input variables?
2. What is the value of *E. bosistoana* trees for peeling?
3. Sensitivity analysis of the variables to see how the value changes and which are the most important factors.
4. How is the value of peeling *E. bosistoana* comparing to peeling *P. radiata*?
5. Is producing posts as a by-product financially viable?

Literature review

Current veneer making industry in New Zealand

Based on the FOA Facts and Figures in 2018, *P. radiata* forests dominate New Zealand forestry by covering a proportion of 90% of the total plantation forest area. Currently, the majority of the forestry resource in New Zealand is exported (NZFOA, 2018) in low value products like roundwood. Considering forestry is the second largest New Zealand industry and one of the foundations of the country's economy, large benefits to the nation can be achieved by increasing the amount of forest resources processed domestically because more value can be realized, and occupation opportunities can be generated. LVL as a valuable structural product, is more valuable than logs, however, the resource is limited to *P. radiata*, of which the low stiffness deficiency is the major drawback for it to be used to produce high quality LVL veneers (Ferguson, 2014). Even after spending more than NZ$1 billion on the breeding of *P. radiata* over the last 40 years, New Zealand forestry has not yet solved the stiffness problem (Walker, 2007). This study looks into using *E. bosistoana* as the alternative to *P. radiata* for structural veneers.

Wood biology/property of *E. bosistoana*

E. bosistoana, also referred as Coast Grey Box, is an evergreen tree species with a small rounded crown that favours fertile, well-drained sites (Nicholas & Millen, 2012). The species appears in mixed forests on east Australia from New South Wales to eastern Gippsland (Boland et al., 2006). *E. bosistoana* log can reach an MoE (module of elasticity) of more than 20 GPa (McGavin, 2016; Australian Standards, 2006), which is almost doubled the stiffness than average *P. radiata* trees. However, it was reported that high level of growth-stress is the main obstacle for *E. Globoidea* to make veneers (Guo, 2018). *E. bosistoana* is stiffer than *E. Globoidea* with higher growth strain (Australian Standards, 2006). A compression force in the centre and tension in the outside of the stem are generated (Kubler 1987) because of the newly formed cells (Guo, 2018). It is still unknown how such large stresses are generated in *Eucalyptus* trees from a molecular mechanism point of view based on existing studies (Guo, 2018). When the stress is released by cutting into the stems, defects such as severe end-splitting can occur (Archer, 1987; Arnold et al., 2013) and influence the yield of veneers significantly.

Existing researches and experiments targeting *E. bosistoana*

A collaborative *Eucalyptus* research project and breeding plan was concerned and initiated by NZDFI in 2008, since when multiple tests for suitability were conducted. *E. bosistoana* was chosen for its strength property, natural-durability and ability to grown well in New Zealand climate (Millen et al., 2018). It is believed to be possible for up to 100,000 hectares of durable *Eucalyptus* forests to be established between 2020 to 2030 (Millen et al., 2019). As discussed before, the high growth stress of *E. bosistoana* is an issue for veneering, however, it is suggested that the growth strain problem can be reduced by systematic breeding and selection program because it is heritable (h^2=0.63) and highly variable between trees (Davis et al., 2017; Guo, 2018). It is worth noticing that, the growth strength has a 0.76 positive correlation with stiffness which is *E. bosistoana*'s major advantage for making veneer (Davis et al., 2017). It is to say that if the breeding projects select to reduce growth strain, it might produce a less stiff product. So, an economic analysis is required to support making decisions of whether reducing growth strain or increase stiffness is more important in maximizing the breeding gain.

The spindled lathe and the spindle-less lathe:

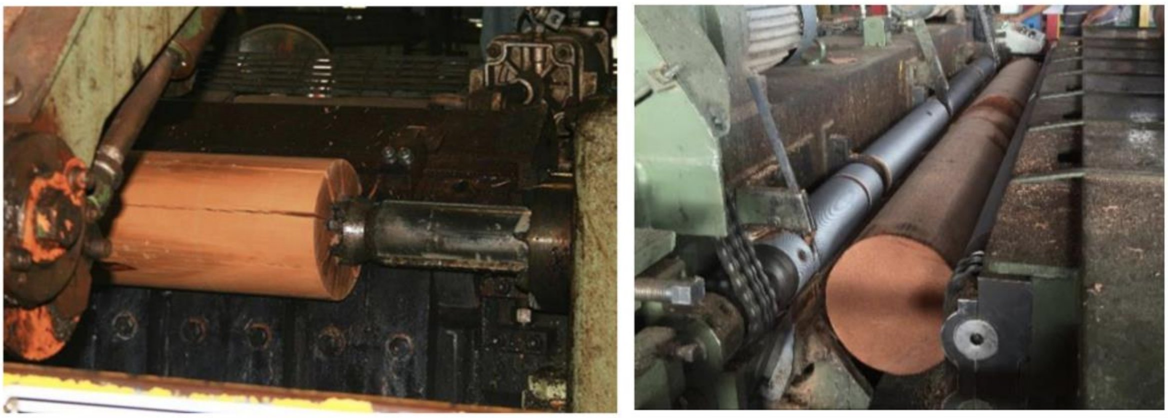

Figure 1: Tranditional spindled lathe with a billet end split (left) and spindle-less lathe (right). Source: McGavin, 2016

In Australia and China, the spindle-less lathe has been extensively used to produce veneers (McGavin, 2016; Arnold et al., 2013). In fact, China has established a well-developed industry on the base of this peeling technology (Arnold et al., 2013). A traditional spindled lathe built by Raute Ltd. is the common machine used for veneer peeling in New Zealand which produces 82 mm peeler bolt.

McGavin’s study in 2016 reported that a spindled lathe used a spindle to hold the end the log and rotated the log with it(shown in Figure 1, left). Logs are peeled into veneers by pressing a knife against the direction of the rotation. Although efforts were spent in the Australian peeling industry to improve this technology in terms of reducing the billet (core) size, there are inherent limitations because of the way the machine works. Limitations include that the peeler core size has to be bigger than the spindle to avoid damaging the machine and that a certain spindle size is required to provide enough torque to peel logs especially at the outer part of a big log where the required feeding force is high. Despite the limitations, significant improvements were achieved by engineers, however, these improvements make the machine more complex and more expensive which is a drawback as more capital investment is needed. Also, the technology applies tension radially to logs while peeling, together with the force of the spindle on the end, logs are prone to end split which is a severe deficiency for processing species like *E. bosistoana* of high growth strain.

Spindle-less lathe on the contrary, does not have a spindle pressing the end of the log as shown in Figure 1. McGavin also reported about the spindle-less lathe technology in his study conducted in 2016 which was explained in the following paragraph. A spindle-less lathe has series of powered rollers parallel to the knife that rotate and peel the logs. Comparing to a spindled lathe, a spindle-less lathe produces much smaller cores of only 20-50mm and it compresses the log while peeling which prevents end splitting instead of promoting end splitting. In fact, the yield was reported to be more than doubled when peeling juvenile *Eucalyptus* trees for veneers. Overall, this technology is suitable for fast-growing hardwoods like *E. bosistoana* that are actually less optimal for veneer making.

E. bosistoana and naturally durable posts

E. bosistoana heartwood is naturally durable for being rich of extractives, the heartwood formation of the species is early (as early as at 2 years old) (Mishra, 2018). It can reach level 1 durability classes (Australian Standard, AS5606-2005) with more than 40% of heartwood (Millen et al., 2019) which makes it competitive in producing naturally durable posts. NZDFI recommended that Marlborough is ideal for planting *E. bosistoana* for the well-drained soil and dry climate that reduces the pests and diseases significantly (Millen et al., 2018). The vine industry is prosperous in Marlborough as almost half (38) of the 77 winners from the 2018 New Zealand Wine of the Year Awards were from Marlborough. Posts are an important consumable for the vineyards, however grape planters has to choose the CCA treated *P. radiata* posts or non-wood posts. It is believed in the vine industry that the inorganic posts in the yards will affect the taste of the vine produced and there is a price premium for organic vine using grapes from organic vineyards (Paul Millen, presentation for School of Forestry Case Study Students, April 2019). To be qualified as an organic vineyard, there should not be any treated product or chemically produced product in the soil (Biogro certification NZ). This pursuit of being organic might indicate a preference and a stable market for naturally durable wood posts made from *E. bosistoana* heartwood in the region (Millen et al., 2017). Some vineyards in Marlborough claim that a post is usually replaced before meeting its guaranteed durability service life because the operating machines frequently damage the posts that are visually hard to see behind the grape plantations (Paul Millen, presentation for School of Forestry Case Study Students, April 2019). As a result, although posts produced with young *E. bosistoana* plantation is not as durable as CCA treated *P. radiata* posts, they are considered mostly durable enough for the vineyards.

Data& Method

A model on a software called R Studio was developed by Altaner and adjusted for this study. The model is able to output a series of tables and graphs by inputting different sets of variables. Sensitivity analysis were done by comparing the difference in tree value by changing value point/scenarios for each of the interested variables. The important tables and graphs were selected and presented in the results to illustrate the value of peeling *E. bosistoana*.

Data

Tree data

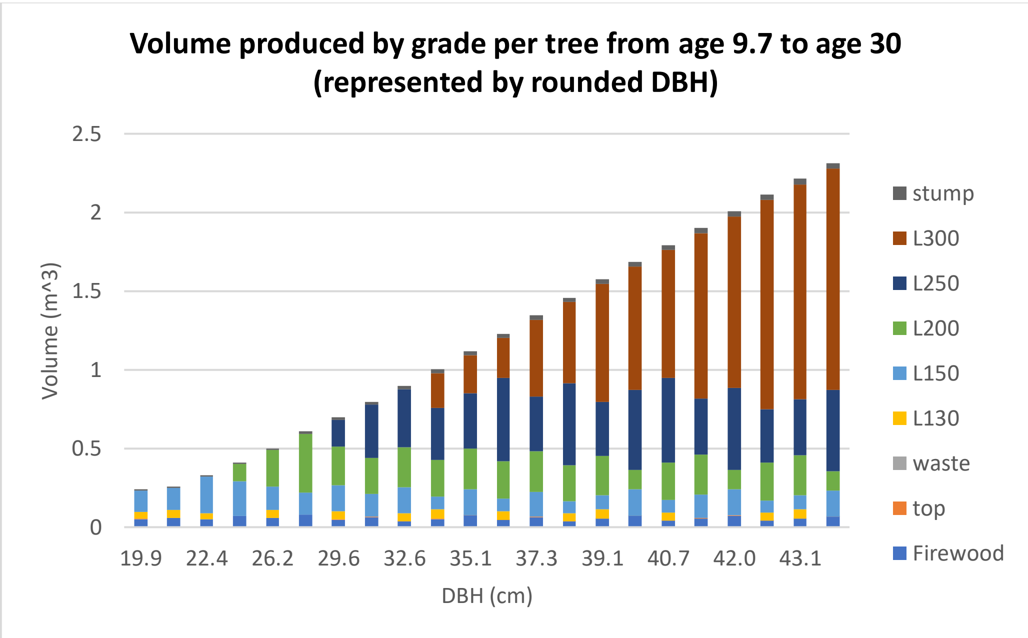

Figure 1: Volume by grade per tree from age from DBH 19.9 to 43,6 cm (age 9.8 to 30)

A set of tree data was used to represent a typical improved *E. bosistoana* tree from age 9.8 to age 30 in New Zealand. It was based on the measurement done in the site established by NZDFI near Craven Road located in the north of Blenheim. *E. bosistoana* open pollination progeny was established in the site and the trees performed very well (Millen et al., 2019). The trees were measured multiple times with a latest measurement in 2019 at age 11, and as a result the average diameter and height was obtained. A growth model and a taper model developed by Buck Forestry Service Ltd. were then applied to the trees, and the tree shape throughout the age was developed. The growth model and taper model was developed for *E. nitens*, and the application of this model is a reconciliated decision for there is no mature plantation in New Zealand to develop a growth model for the species.

Figure 1 above presents the log grade mix of the typical tree from DBH 19.9 cm (age 9.8) to DBH 43.6cm (age 30).

From the bottom to the top of the tree, the logs are graded into stump, L grades, firewood, waste and top. The bottom 0.2 of a *E. bosistoana* tree is curling and is usually not extracted during harvesting operation for being not very valuable and the potential of coppicing. One L grade log needs to be longer than 2.7m with an SED of over 13cm. There are two different types of firewood in the tree data, grade 1 with an SED of greater than 8.3cm to 15cm and grade 2 with an SED in the range of 8.3cm to 5cm (also need to longer than 2m). In this study, the firewood grades were combined into one for simplification purposes. The waste is the part above firewood, logs with an SED in between of 8.3cm to 5cm are categorized into this grade. The top is the highest portion of the tree with a LED (large end diameter) of less than 5cm. An assumption was made that the tree would be cut into 2.7m logs as it is a widely recognized veneer length. Each piece of log exceeds the SED for the cut-off points were put into the grade (L130 stands for the 2.7 m log with SED between 13cm to 15cm).

Product value and veneer price data:

Table 1: Veneer grades and prices – JNL data and tested scenarios

Veneer Price by Grades				
VeneerClass	VeneerClassMoE (GPa)	JNLValue (NZ$/m^3)	Estimated (NZ$/m^3)	EstimatedNoPremiumAfterF13 (NZ$/m^3)
nonstructural	0	55	55	55
F05	6.9	374.4	374.4	374.4
F07	7.9	405.6	405.6	405.6
F11	10.5	421.2	421.2	421.2
F13	11.3	436.8	436.8	436.8
F17	14		445.6	436.8
F22	16		453.6	436.8
F27	18.5		460.5	436.8
F34	21.5		466.4	436.8

The original veneer price data provided by JNL (Junken New Zealand Ltd) is in US$ and was converted into NZ$ using an exchange rate of 1.56 NZ$/US$. The data only covers veneer F05 to F13 in which F13 is already an estimated value by the company because there is no market for higher grade veneers in New Zealand. No supporting data were found indicating how veneer price increases with the increasing of veneer MoE by surveying Chinese veneer peelers. However, it is believed that there is a 30% premium for the supper stiff LVL with

MoE of over 16GPa (Millen et al., 2019). Although it is considered that higher graded veneers were more valuable, it is impossible to accurately predict how the market will perform. So, a conservative assumption was made that there could be no price premium for veneers above F13 and this scenario was used as the base pricing in the study.

The alternative scenario for the price gradient is by modelling how the price increases. Microsoft Excel was used to generate an equation for the task. A line was fitted logarithmically for the available price data and the equation

Price = NZ$44.269 ln (grade difference to F07) + NZ$374.33

that has a R^2 value of 0.9978. Apply the equation to the unknown prices of the structural veneer grades, the estimated veneer prices with a premium for stiffer product was obtained.

Input variables

Table 2: Table of input variables and sources

Input Variable Table		
Variables	**Value Tested**	**References/sources**
Stiffness profile (pith-bark)	*E. bosistoana* (9-21) GPa *E. nitens* (10.7-15.7) GPa *E. globulus* (10.5-18.9) GPa *P. radiata* (*3-12*) GPa	Australian Standards (2006) McGavin (2016) McGavin (2016) Gaunt et al. (2003); Xu & Walker(2004)
Conversion ratio (without core, after shrinkage)	High/*P. radiata*: *0.7* – *E. nitens/ E. globoidea* Medium: *0.4* – *E. globoidea* Low: *0.25 - E. globoidea/ E. urophylla x grandis*	Blakemore et al. (2010); Guo (2018) Guo (2018) Guo (2018); Arnold et al. (2013)
Volumetric Shrinkage	High: 0.28 Medium: *0.20* Low: 0.15 P. radiata: 0.095	Sharma et al. (2017) Chafe (1987) Carlos et al. (2013) Harris & McConchie (1978)
Veneer price	With price premium (± 10/20%) No Premium (± 10/20%)	JNL data + fitted line JNL data + no premium after F13
Peeling machine (Core size)	High: *130* mm – extreme case Medium: 82 mm – NZ typical core size Low: *30* mm – spindle-less lathe	McGavin (2016) JNL/NPI (2019); Guo (2018) McGavin (2016)
Posts regime ($NZ/m3)	High: $1,316.07 (70mm x 2.7m) Medium: $612.96 (85mmx2.3m) Low: $368.99 (127.5mm x 2.7m) Waste: $55	Accoya® (acetylation) (> H4) Wood-Shield Pty Ltd (untreated with polyethylene plastic coating and cap) Kiwitimber (H4 CCA) MPI - Jun quarter weighted average price for domestic pulplog

Variables in red are controlled while testing other variables
Italic numbers are rounded/average of a value range based on the references

Table 2 above displays the variables that were derived from existing studies and tested in the study. For each variable, multiple values such as a reasonable high/medium/low value; cross comparison to related/ competing species or different regimes were tested. The italic numbers are an average value of either multiple values from different studies or a range of value from one paper.

1. *Stiffness profile*: The stiffness profile is the MoE distribution from pith to bark. Australian standard, in 2006 reported an average *E. bosistoana* MoE range of 9-21 GPa at age 45. Using stiffness data gathered from mature trees might seem optimistic for the study, however, the tree measured in Australian Strandards are average stem MoE from unimproved trees. Another study discovered that 15-year-old primarily improved *E. bosistoana* can produce veneers with stiffness of as high as 19.4 GPa (Altaner et al., 2019). So, with proper selection, it is possible for the tree to reach a maximum radial MoE of 21GPa. Other values tested are 10.7-15.7 GPa for 20 to 21-year-old E. nitens commercial plantation (McGavin, 2016), 10.5-18.9 GPa for 20 to 21-year-old E. globulus plantation (McGavin, 2016) and 3-12 GPa for NZ plantation *P. radiata* (Gaunt et al., 2003; Xu & Walker, 2004).

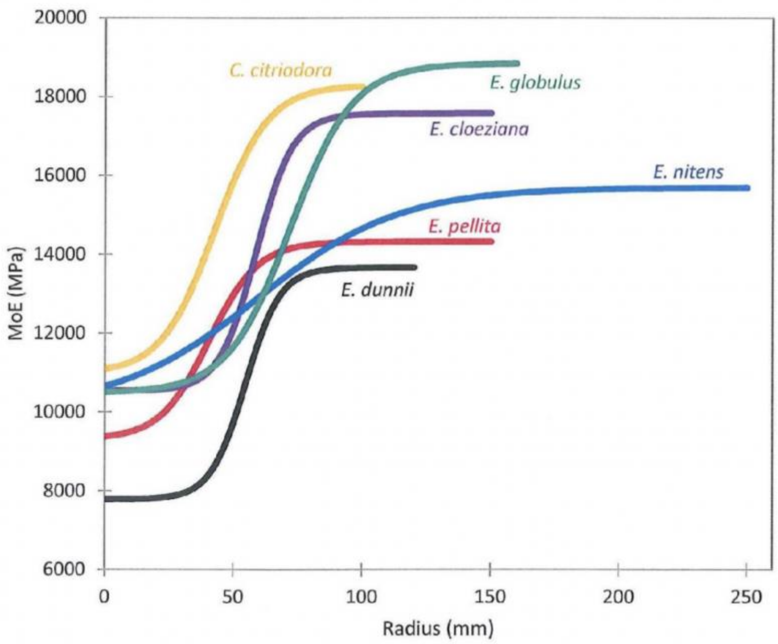

Figure 3: MoE against radius curve for six Eucalyptus species (source: McGavin, 2016)

By comparing Figure 3 above and Figure 4 below, it was noticed that although the stiffness distribution curve McGavin used are different than what was used in the study, they were in similar shape at the radius range (> 30mm) in which the log well be made into veneers. The stiffness curves in other studies done by Gaunt et al., 2003 and Xu & Walker, 2004 are similar to the profile displayed in Figure 4.

2. _Conversion ratio_: The conversion ratio is a complex variable as in different studies there are different ways of calculating it. This study considers the conversion ratio as the ratio of the usable veneers to the volume of the peeled cylinders without considering the effect of shrinkage, defect core or round-up loss. This means that the only main factor affecting conversion ratio is how much veneer produced are defected. However, there are studies that calculate conversion ratio as the percentage of the total usable product to the peeled logs which covered the volume deduction caused by having a peeler core, shrinkage, roundup loss and veneer defect (Blackmore, 2010; Arnold et al., 2013). To revert the conversion ratio back to form that the study required, a series of calculation were done using the equation:

$$\text{Conversion ratio} = 1 - \frac{(1 - Volumetric\ shrinkage) \times (1 - \%roundup\ loss) \times (1 - \%Core)}{Product\ yield}$$

   The equation is a reversing manipulation of how the product yields in the mentioned studies were calculated.

   Because little conversion ratio study for *E. bosistoana* was found, alternatively, other *Eucalyptus* species of similar properties were referenced. A high value of 0.7, a medium value of 0.4 and a low value of 0.25 for *E. bosistoana* and an average 0.7 for *P. radiata* were considered reasonable.

3. _Volumetric shrinkage_: Studies displayed in Table 2 above indicate that the reasonable high/medium/low volumetric shrinkage for *E. bosistoana* is 0.28 (2-year-old plantation), 0.20 (age not mentioned), 0.15 (42-year-old shelterbelt trees) respectively. *P. radiata*, on the other hand, is more dimensionally stable given that 0.095 is a typical volumetric shrinkage value.

4. _Veneer price_: The pricing scenarios discussed previously with a price adjustment of ± 10/20% were tested for the sensitivity analysis.

5. _Peeling machinery (core size)_: Currently in New Zealand, a Raute peeling lathe is commonly used by peelers like NPI (Nelson Pine Industry Ltd.) and JNL which produces 82mm peeler cores. However, some spindle lathes produce peeler core of up to 13 cm while a spindle-less lathe only produces a core of 2-5 cm (McGavin, 2016). So, the high/medium/low value used were 130mm, 82mm and 30 mm.

6. *Post regimes*: Because there is currently no naturally durable *Eucalyptus* post in the market, the price of three other types of posts were used to represent the possible value of the *E. bosistoana* posts. They were made from different material, technics and are different in size, however, *E. bosistoana* posts should be able to serve the same application if not better in vineyards. The value used in the sensitivity analysis was 0.5 of the marketing price of the product because of a robust assumption assuming that the heartwood as a material cost as same as half of the posts' price. The high value posts used was acetylation treated *P. radiata* posts produced by Accoya® with a value of NZ$1316/m^3. The post used for the medium value was an untreated P. raidata post with polyethylene plastic coating and cap produced by Wood-Shield Pty Ltd. with a value of NZ$613/m^3. The low post value was represented by Kiwi Timber's CCA treated *P. radiata* post with a value of NZ$369/m^3.

Method

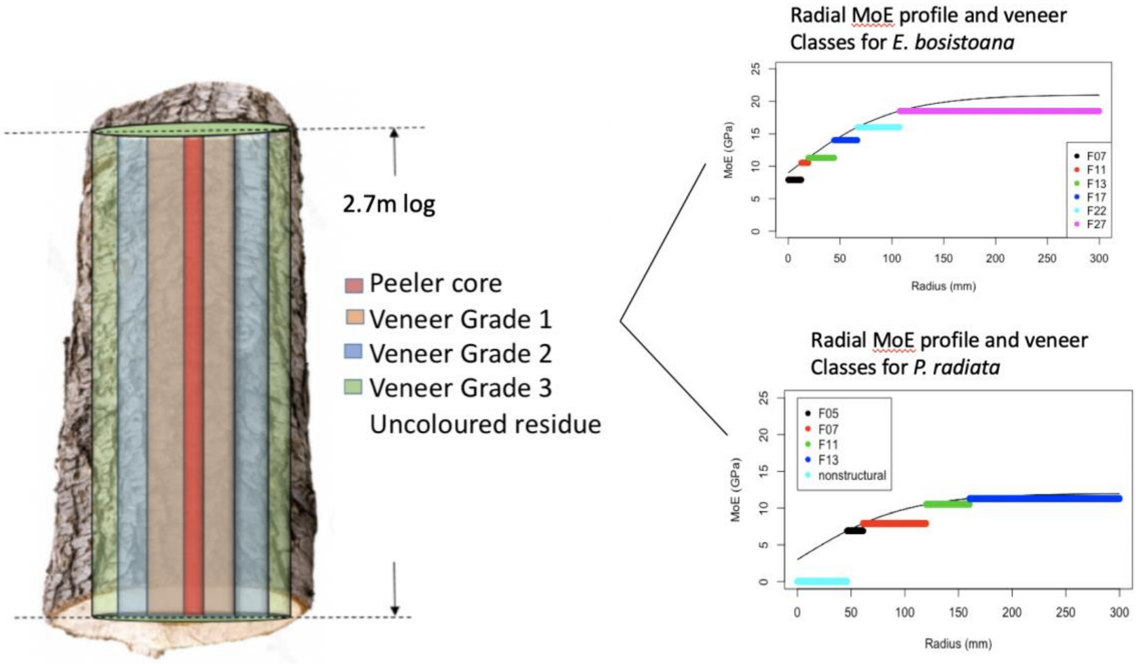

Figure 4: Display of the veneer grade assignment and comparison of P. radiata and E. bosistoana

Figure 4 above is a schematic diagram explaining how the value was evaluated. As mentioned previously, the tree has been graded to represent 2.7m logs after a first cut. To produce veneers, the log has to be in a cylinder shape rather than the circular truncated cone shape after the first cut. The L grades logs were simulated to be cut into cylinders based on the SED. Within each cylinder, a pith to bark MoE profile was applied which influence the grade of the veneer produced by a specific part of the log using the equation: $MoE = MoE_{Pith} + \tan\left(\frac{Radius}{100}\right) \times (MoE_{Max} - MoE_{Pith})$. In the equation, 100 is the divisor of radius adjusts slope of function to form a curve shaped profile which was fitted by Altaner (2019) and displayed in Figure 4. Veneer grades are assigned based the MoE cutoff points displayed in Table1. The rotary peeling technics produce a peeler core, and this part of log will be extracted and combined with the log waste (when the logs are made into cylinders), the tree-top, firewood and waste wood as non-veneer products. The volume loss caused by roundup loss, shrinkage and yield factor were subtracted from the gross volume of the products and the final merchantable product volume was acquired. Multiply the merchantable volume of each product with prices respectively assigned, the evaluation of a tree was then completed.

Table 3: The input table of base P. radiata and E. bosistoana scenarios

Scenario	Core (mm)	PeelerCoreValue($/m3)	MoEpith(GPa)	MoEmax(Gpa)	Conversion ratio	Shrinkage
EbosBase	82	55	9	21	0.7	0.2
PradBase	82	55	3	12	0.7	0.095

The procedures explained in the previous paragraph was conducted with a model on R Studio developed by Altaner, 2019 and adjusted for the study. An input table (Table 3) with the scenarios to be tested were listed which include core size, core value, pith to bark MoE value, veneer yield, shrinkage, veneer roundup loss. The table also includes a veneer pricing file which represent a pricing scenario. Table above presents the base value of the input variables used in the analysis together with the base roundup loss of 8cm (Guo, 2018). They were the average value of what was stated in the literature/ survey except for the conversion ratio that had the high value set as a base. When one of the variables were changed to be tested, the other input values remained constant.

While analyzing the value of the post regimes, it was noticed that different posts have different diameter and length. So, for each post product, not only the core price but also the peeler core size was changed accordingly. Additionally, a conversion ratio of (0.85 = 2.3m/2.7m) was applied for the post produced by Wood-Shield Pty Ltd as the length of the post was 2.3m rather than 2.7m cuts done for the tree. For other posts, the yield was assumed to be 100%.

Results and interpretation

Comparison of sensitivity

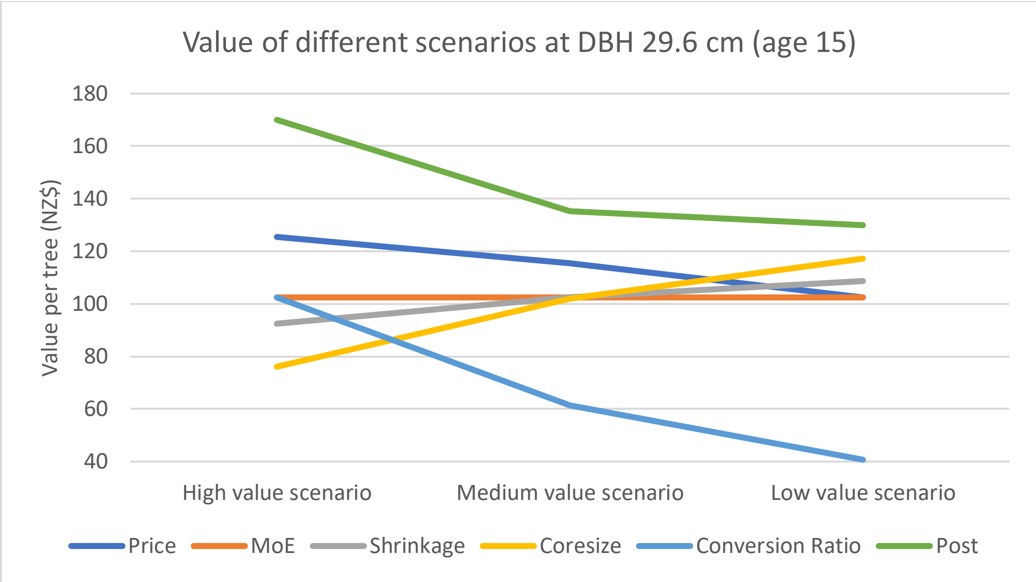

Figure 5: Per tree value of different scenarios at DBH 29.6 cm (age 15)

Figure 5 above displays the value of the a high, a medium and a low scenario in terms of input value of each variable tested at DBH 29.6cm (age 15 on Craven Road). The graph indicates that a higher shrinkage value or a bigger peeler core reduces the per tree value of peeling *E. bosistoana* while the other values have a positive correlation. The medium value point of core size and shrinkage crossed is the base case. It is observed that under base case scenario, an *E. bosistoana* tree is around NZ$102 at DBH 29.6 cm. The most important factors are conversion ratio, post regime, core size and veneer prices at DBH 29.6cm given that they have the most drastic value changes from high to low input values. At the low conversion ratio point of 0.25, an *E. bosistoana* tree only produces NZ$41 worth of products after being peeled comparing to the NZ$102 high conversion ratio 0.7. Even the regime in which the least valuable posts were produced, NZ$130 is generated by a tree while the high value post regime makes a tree worth an impressive NZ$170 at DBH 29.6cm. A 130mm core decreases the per tree value to NZ$76 which is around 25%, and a 30mm core produced using a spindle-less lathe increases the single tree value to NZ$117.

No price difference is observed for different *Eucalyptus* MoE profile because the core size of the base case scenario is 82mm and at a distance of 41mm to pith, the log already produces almost no veneer under grade F13. Also, the pricing base scenario assumed that there was no price premium for veneers of grade higher than F13. So, the different *Eucalyptus* MoE profile has different product mix of same prices thus same value.

Volumetric shrinkage is another factor that is not that important based on Figure 5. Part of the reason is that shrinkage simply decreases the value of the veneers in a proportion and the difference between high shrinkage and low shrinkage is not vast. There is only a 0.13 difference between the high shrinkage value and the low shrinkage value which are 0.28 and 0.15 respectively.

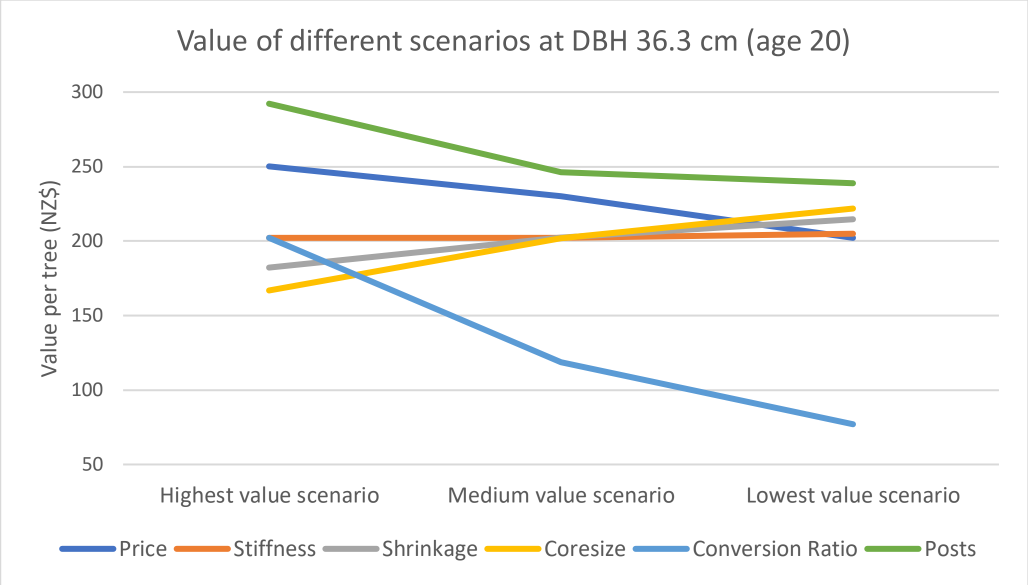

Figure 6: Per tree value of different scenarios at DBH 26.3 cm (age 20)

Figure 6 above indicates that the single *E. bosistoana* tree value under the base scenario is NZ$202 at a DBH of 36.3cm. The scenario of the highest per tree value is the high value post regimes that generates NZ$292 per tree and the least valuable scenario is the one at 0.25 conversion ratio under which one tree is only worth NZ$77.

By comparing Figure 5 and Figure 6, it was noticed that a constant 60% decrease in value appears when the conversion ratio decreases from 0.7 to 0.25 at different DBH. The shrinkage and veneer prices also have similar effect to the value across DBH points. The core size and post regime, on the other hand, are less important as the tree growing bigger in DBH.

Comparison of product composition of *P. radiata* and *E. bosistoana*

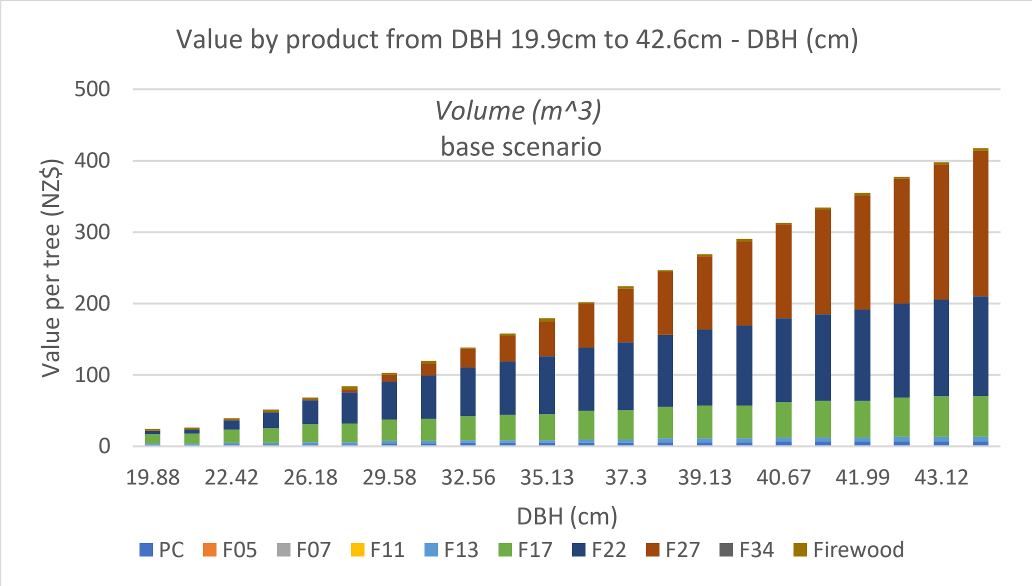

Figure 7: Value by product from DBH 19.9cm to 42.6cm - E. bosistoana base scenario

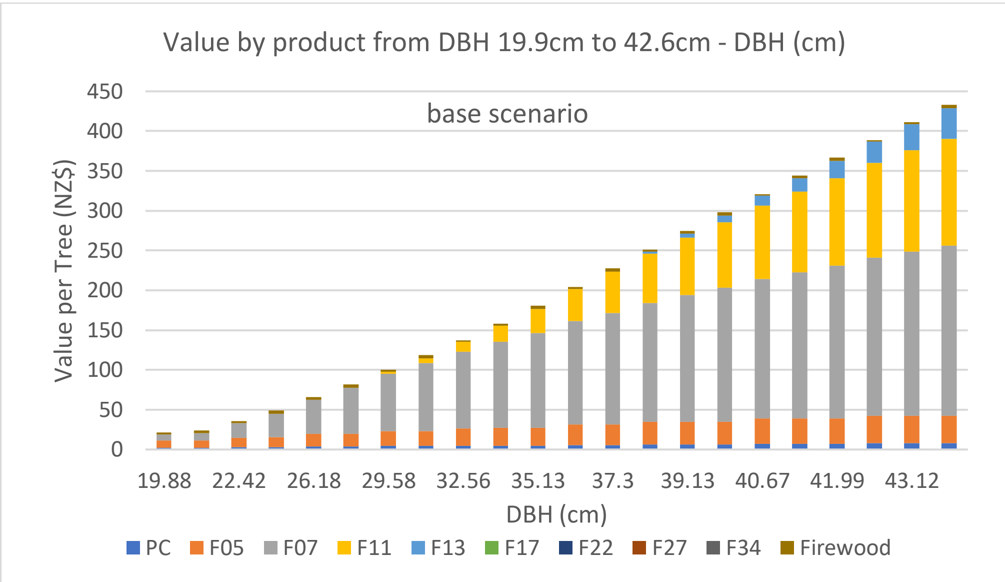

Figure 8: Value by product from DBH 19.9cm to 42.6cm - P. radiata base scenario

Figure 7 and Figure 8 above indicate that, a *P. radiata* tree under base case scenario was estimated to worth NZ$22 at DBH 19.9cm and NZ$434 at DBH 43.6cm while an *E. bosistoana* tree starts at NZ$24 and ends at NZ$419. The increasing of the value is slow when the tree is small, then speed up and remain consistent (more than NZ$20 increment per year) after reaching a DBH of 26.2cm (age 13 in Craven Road) for both species. Firewood and PC (peeler core) cover 20% of the total value when the tree is very small, but the proportion rapidly reduces to less than 6% when it reaches 29.6cm DBH and keeps on decreasing to around 2.5%. Almost no veneer under grade F13 is produced for *E. bosistoana* while only a small amount (less than 10% of total value) of veneer over grade F13 is produced by *P. radiata*. The veneer grade that produces the most value by *E. bosistoana* is F17 before DBH 24.3cm, then F22 veneers dominates the product value mix until the DBH reaches 39.9cm, after which the F27 veneer becomes the product that contributes the most to the tree value. For *P. radiata*, F07 is the main veneer grade regardless of tree size.

Important factors

Veneer price

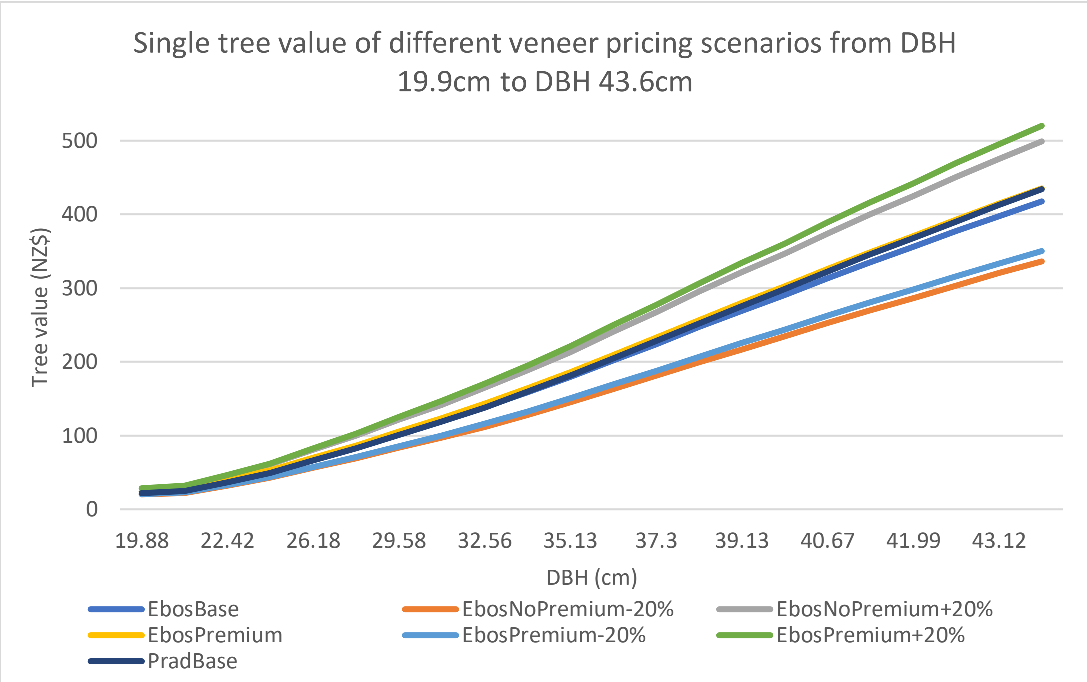

Figure 9: The single tree value of different veneer pricing scenarios from DBH 19.9cm to DBH 43.6cm

Figure 9 above displays that, at a low DBH, different pricing scenarios have similar value of around $29/tree. With the tree getting older, the absolute value difference gets bigger. The value of base *E. bosistoana* scenario is similar to the value of base *P. radiata* model or the price premium model. This is mainly because, the price premium used is very small which is less than NZ$10 per grade after F13 when the per cubic meter price for F13 grade veneers is already at more than NZ$436/$m^3$. But at the same time, the single tree value is sensitive when the prices are changed to ±10/20%. For the high value scenarios with +20% price adjustment for structural veneer grades, one *E. bosistoana* tree with a price premium for being stiffer is worth NZ$520 while the value is NZ$21 less without the price premium.

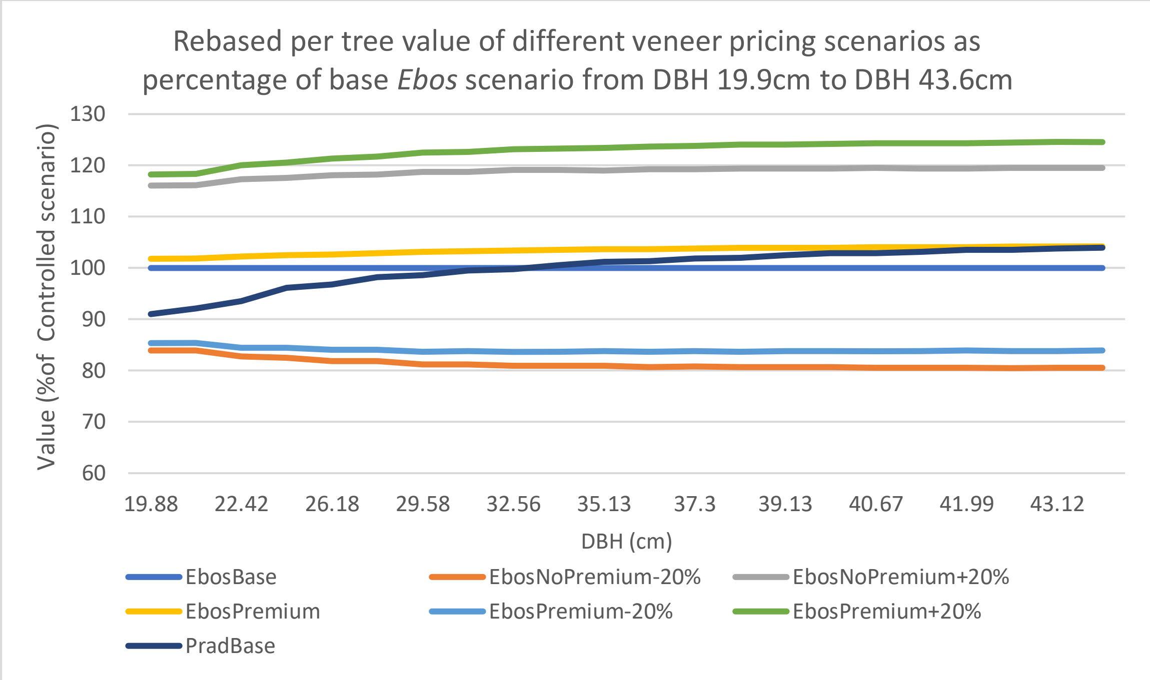

Figure 10: Rebased per tree value of different veneer pricing scenarios as percentage of base Ebos scenario from DBH 19.9cm to DBH 43.6cm

Figure 10 above displays that the per tree value of *P. radiata* is at 90% of the value of a *E. bosistoana* tree at DBH 19.9cm However, this inferior in value is eliminated at DBH 32.6cm, after which *P. radiata* is more valuable. By the time the DBH reaches 43.6cm, *P. radiata* is about 4% more valuable than *E. bosistoana* in making veneers. However, with a price premium, *E. bosistoana* trees are more valuable than *P. radiata* regardless of size.

Conversion Ratio

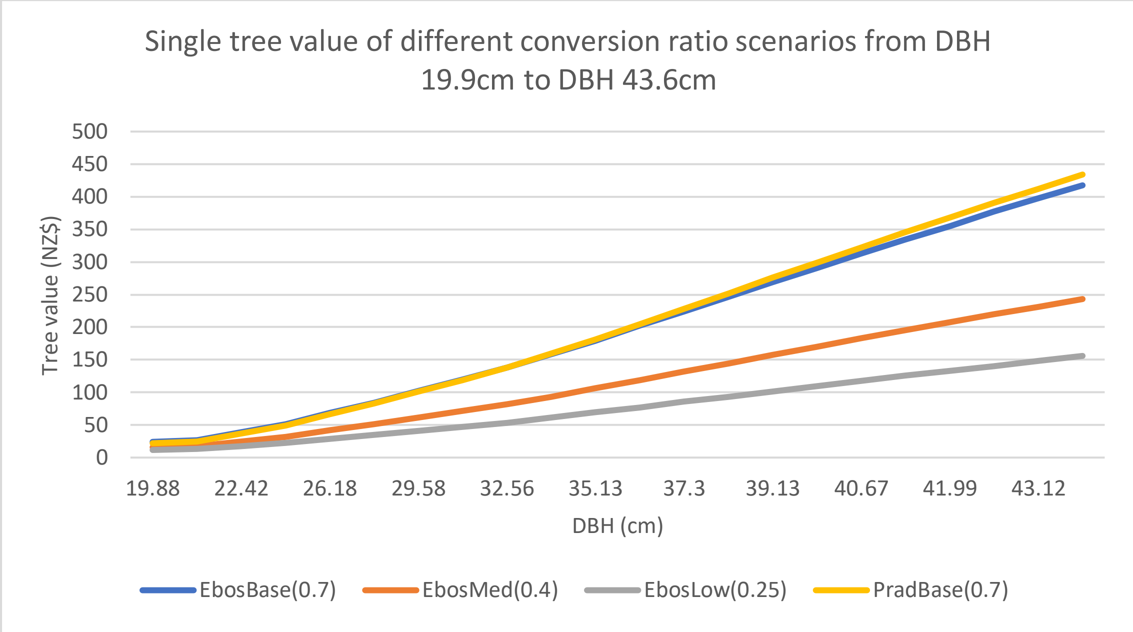

Figure 11: Single tree value of different conversion ratio scenarios from DBH 19.9cm to DBH 43.6cm

Figure 11 above presents how the conversion ratio is one of the most important variables to the value of peeling *E. bosistoana*. When the tree reaches a DBH of 43.6cm, the per tree value of 0.7, 0.4 and 0.7 conversion ratio is NZ$418, NZ$233 and NZ$156 respectively which are drastically different. This indicates that a successful *E. bosistoana* plantation resources for veneers need to be one of good veneer yield ratio.

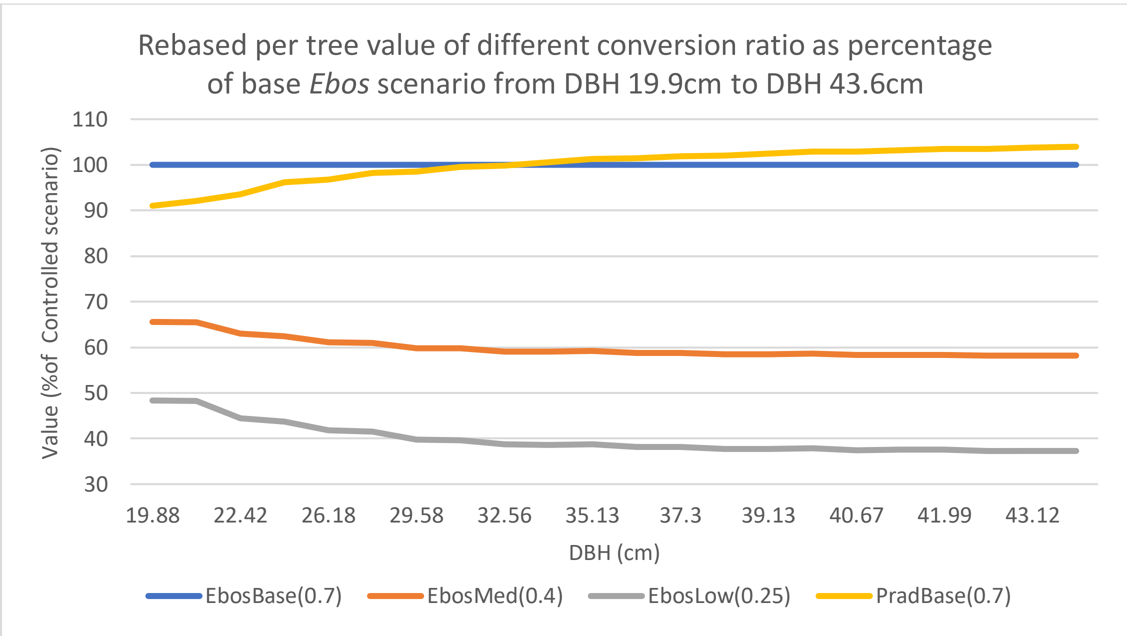

Figure 12: Rebased per tree value of different conversion ratio as percentage of base Ebos scenario from DBH 19.9cm to DBH 43.6cm

Based on Figure 12 above, when the trees are small, less difference in per tree value is observed. A yield of 0.25 is 35% of 0.7 and Figure 17 above indicates that the value of one tree with 0.25 yield is of 50% the value of a tree with 0.7 conversion ratio. The rebased value as percentage of the value at 0.7 yield decreases with the tree getting bigger and flattened off to a level of 37%. This trend of percentage value gradually decreasing is because only veneers are affected by the conversion ratio and with the tree getting bigger, the value proportion of veneer gets bigger and therefore higher difference in value realized.

Post regimes

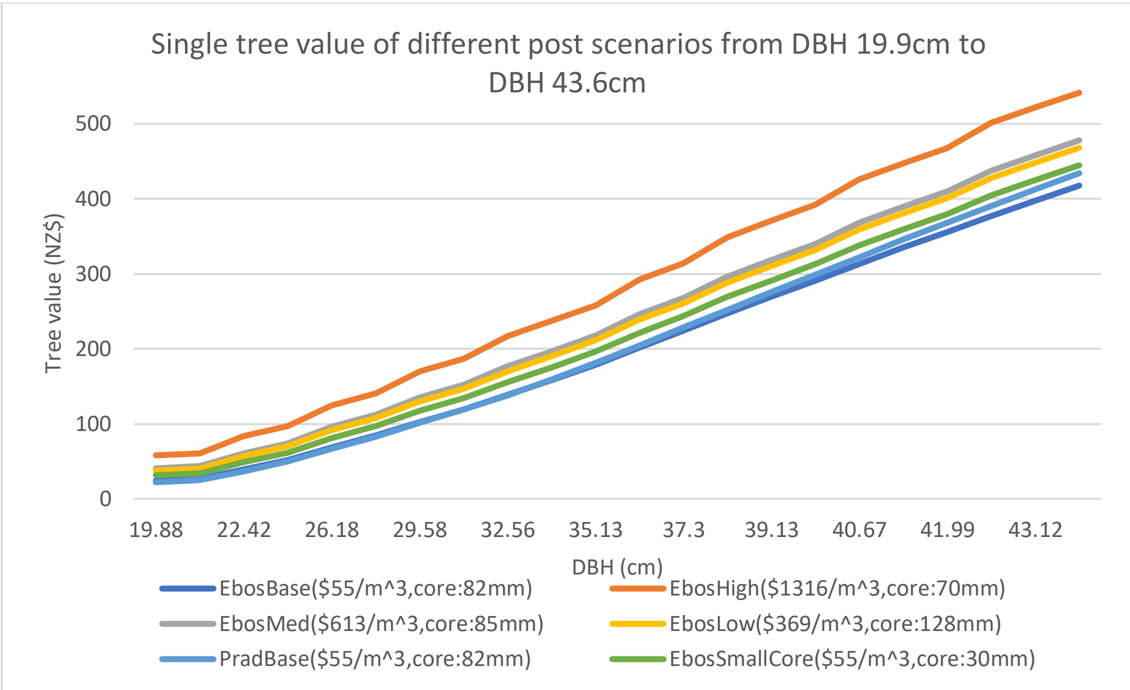

Figure 13: Single tree value of different post scenarios from DBH 19.9cm to DBH 43.6cm

Figure 13 indicates the per tree value when the peeler core is made into different products including firewood, high value posts, medium value posts and low value posts. The results are also compared with the 30mm peeler core scenario using a spindle-less lathe with the cores being made into firewood. A unique changing pattern that is more toothed than other scenarios was observed. This is because a specific length (2.7m for high/low price posts and 2.3m for medium price posts) is required to make posts. And every time when the trees grew enough to make a new post, the value of the tree jumps, and after the jump, the increase is in similar pattern as other variables. By producing high value posts that worth NZ$1316/m^3, one *E. bosistoana* tree can worth NZ$540 at DBH of 43.6cm. When medium

(NZ$613/m^3) or low (NZ$369) value posts are produced, a tree is worth NZ$477 and NZ$468 at DBH 43.6 respectively. It is observed that, by producing a small core with spindle-less lathe or making the core wood into posts, the per tree value of *E. bosistoana* is higher than *P. radiata* regardless of size. Also, making even the least valuable posts will result in a higher per tree value than having a very small core (3cm) of firewood and producing more veneers.

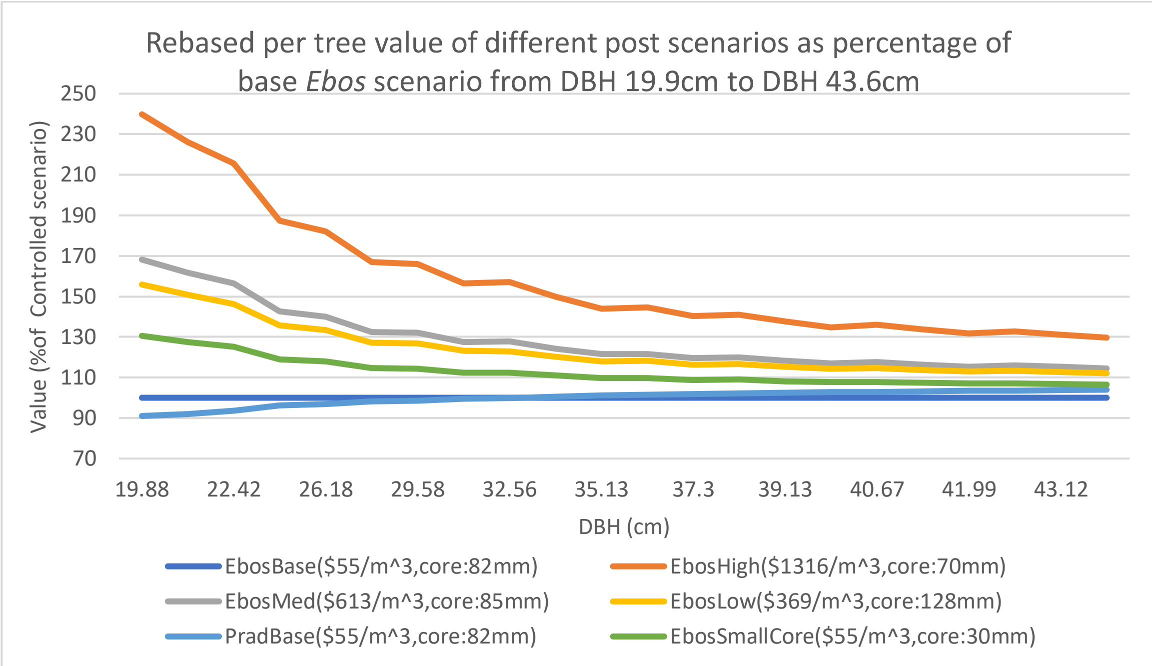

Figure 14: Rebased per tree value of different post scenarios as percentage of base Ebos scenario from DBH 19.9cm to DBH 43.6cm

Figure 14 above supports that, with the tree getting bigger, the influence of core value is less to the value of the whole tree. This is because the size of the posts are constant while the trees are growing, and the proportion of posts in the total tree value is reducing.

MoE profile with price premium

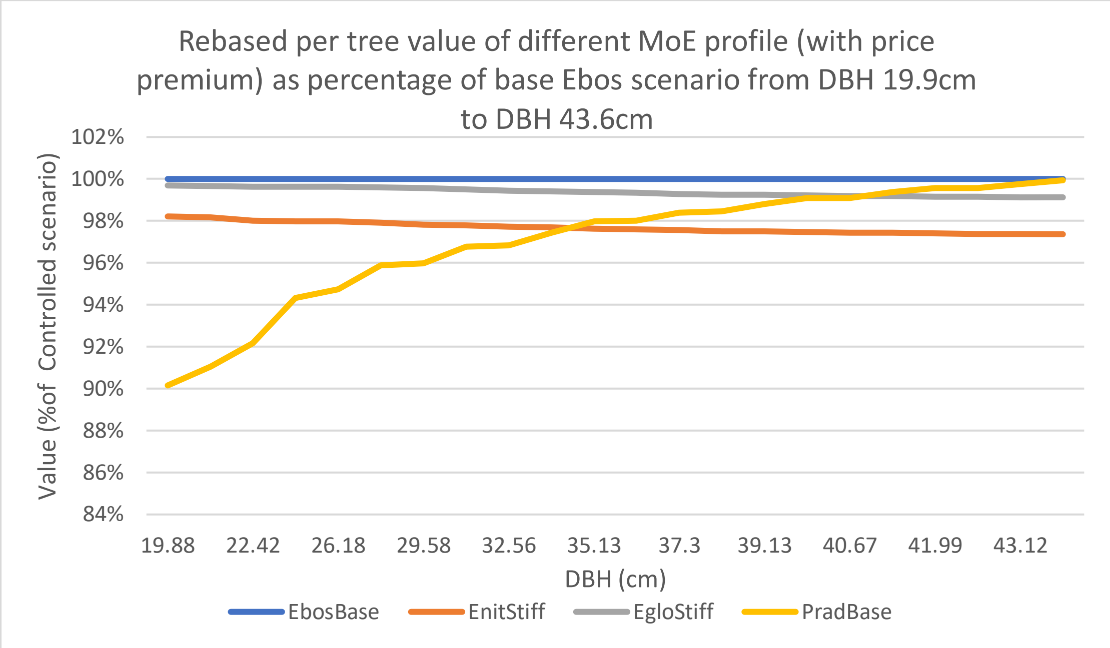

Figure 15: Rebased per tree value of different MoE profile (with price premium) as percentage of base Ebos scenario from DBH 19.9cm to DBH 43.6cm

Figure 15 displays the per tree values among different MoE profiles with a price premium. It was discussed previously that no value difference was found for different MoE profile using base pricing data which was no price premium for veneers over grade F13. Figure 15 indicates that, even with a price premium, different *Eucalyptus* MoE profiles only alter 1%-2% of the per tree value. So MoE profile is still a less important factor even with a price premium for stiffer products. This is because the MoE difference between tested *Eucalyptus* species are minor, and price premium is less than 5% per grade improvement after grade F13.

Per hectare/ per cubic metre value

Table 4: Value per hectares (600 SPH) and value per m^3 *for E. bosistoana at a DBH of 29.6cm.*

	High value scenario		**Medium value scenario**		**Low value scenario**	
(NZ$)	Value per hectares	Value per m3	Value per hectares	Value per m3	Value per hectares	Value per m3
Veneer Price	75270	179	69318	165	61466	147
MoE profile	61466	147	61466	147	61466	147
Volumetric shrinkage	55478	132	61466	147	65209	155
Coresize	45659	109	61261	146	70318	168
Conversion Ratio	61466	147	36771	88	24423	58
Post	101996	243	81217	194	77953	186

In the stage report done by NZDFI in 2019, an economic feasibility analysis for growing *E. bosistoana* was conducted which targeted 600 SPH (stocking per hectares) for the peeling regime. Applying the 600SPH to the per stump volume, a per hectare value of NZ$61,466/ha was acquired for the base case *E. bosistoana* scenario at DBH 29.6cm. It increases the total value per hectare to about NZ$78,000/ha by producing a low value post, while the high value post regime can exceed NZ$102,000/ha. It is worth noticing that the table presents the value of the product made by the trees from a peeling factory, and how much the trees are worth for growers depends on the proportion of product value peelers would like to pay as wood material costs. Assuming the peelers are willing to pay 30% of the total value as costs for purchasing logs, the tree value in one hectare for growers drops to around NZ$23,000/ha under base scenario at DBH 29.6cm.

Table 4 above also presents the per cubic metre value of a *E. bosistoana* tree under different scenarios. At the base scenario, NZ$147/$m^3$ is reported and with a price premium, the value increases to NZ$165/$m^3$. By producing posts, the low/medium/high value post regimes generate NZ$186, NZ$194 and NZ$243 for one cubic metre respectively. It is also presented that under a medium conversion ratio scenario of 0.4, the *E. bosistoana* is only worth $NZ88/$m^3$.

Discussion

Presentation of the results

Originally, the results were derived on an age basis and the x axis of the graphs is tree age. However, as the tree size in correlation of the age only apply to the site where the data were collected (Craven Road), the value were plotted against DBH. Readers can fit the results of the study to their own regimes according to the DBH and therefore estimate the value of their trees. This way of presenting results significantly widened the application range of the study, but there are also limitations. On a silviculture perspective, the trees are often different across different sites in terms of shape and wood properties (Fielding, 1976). The tree shape includes straightness and taper vastly affects the value can be realized from the trees by affecting the yield because, a straighter tree with more cylindrical shape has less waste while being made into veneers. Other properties such as growth strain affects value realization by influencing the veneer defect ratio. Growers are recommended to conduct assessment of the wood properties on their sites before putting the result of the study into practice.

Limitations associated with the model and input variables

Model:

It was assumed that all the trees have similar growth and form which could only be achieved by establishing a clonal plantation forest.

A value rounds up had to be done while making an MoE profile because of a bug associated with R Studio. The bug makes the effect of MoE profile less pronounced, however, and it should not affect the results as the difference is minor and insignificant.

The difference considered in the study between *P. radiata* and *E. bosistoana* is the MoE profile, shrinkage and the possibility of having a smaller corewood or make durable posts from peeler core as a byproduct. The tree data would not represent the shape and growth of *P. radiata* growth either. *P. radiata* scenario exists to test how would *E. bosistoana* perform with the advantage/disadvantage of being a stiffer species and the potential of producing a valuable byproduct. It is also a benchmark for the peelers to decide if the results are accurate for they understand the value of *P. radiata*.

Veneer prices and MoE Profile: The limitation and reconciliation of the veneer pricing scenarios and MoE profile scenarios were discussed in the method session as they were the main assumptions in the study.

Conversion ratio: The base conversion ratio used was the high value which was realistically higher than what an average *E. bosistoana* tree would achieve. However, considering that the 0.7 conversion ratio can be achieved by selection, pruning (Guo, 2018; Davis, 2017; Blackmore et al., 2010) and the heritability of stress grain (the main factor affecting conversion ratio) is really high (Davis, 2017), it was considered achievable. It is, in some way, unfair to compare a plantation species at the starting stage to *P. radiata* which has been improved for 40 years with hundreds of million dollars spent. But the fact that the current average conversion ratio is around 40% based on existing studies need to be stressed. This indicates that the base value is not what growers will gain now without proper breeding/selection/pruning, it is a possible value *E. bosistoana* can reach with a few years of improvement.

In practice, some of the defect veneers can be remanufactured by stitching or applying multiple layers of defect veneers as normal grade veneers (Arnold et al., 2013). These practices can increase the conversion ratio which was not considered or reflected in the analysis.

Volumetric shrinkage: The use of volumetric shrinkage is a tree average value, although it is considered accurate enough to represent how the trees will perform in drying processes, it can be inaccurate because outer wood and corewood have different shrinkage ratio. This radial difference will affect the veneer yield of each grades and the estimated value. Also, in practice the posts will be air dried while veneers/firewood are targeting different moisture content during drying. However, the shrinkage values applied in the study were always targeting 0% moisture content (Oven-dried).

Post regimes: The rough estimation that the post manufactures would pay 50% of the post price as the price for pre-manufactured post size logs is not likely to be accurate. For it is considered that no more processes are required once the *E. bosistoana* is peeled as it is naturally durable. Nevertheless, the 50% assumption makes the result conservative and compensate problem associated with the overestimated post yield (default 100% in the model).

Veneer visual gradings

One of the problems associated with *Eucalyptus* is that, it was reported in 2014 by McGavin that a low proportion of high visual grade veneers (less than 30% of A/B/C Grade) were produced using a spindle-less lathe. As the majority of the veneers produced will be grade D which is technically acceptable for the majority of the structural face veneers or structural/non-structural core veneers, the higher-grade veneers are more demanded. This implies potential problems of using *E. bosistoana* only to support the veneers industry in New Zealand. However, effective pruning operation or gum pocket removal can improve the yield of grade C or higher grades to up to 60% or 50% respectively (McGavin, 2014). Alternatively, *P. radiata* appearance grade veneers are suitable to be face veneers which indicates that the using *P. radiata* for veneers will not cease without solving the problem. It was also reported that more than 16% value gain can be acquired by the pruning or gum removal of *Eucalyptus* trees (McGavin, 2014). So, the per stem value can differ a lot with the consideration of the visual grading of the veneers but it is not covered in the study.

Price premium and comparison to Ferguson's study

Ferguson, in 2016, studied about in the economic gain of producing higher stiffness *P. radiata* veneers. However, the assumptions and methods in his study are drastically different from this study. In his study, he extracted a price premium using the prices of different LVL grades and applied the premium to a surveyed veneer price and estimated the price of the rest grades. He reported a price premium of 1.98 by increasing the veneer MoE from <8GPa to 11-13 GPa and a premium of 2.43 from <8GPa to >13GPa. The price data provided by JNL does not cover non-structural veneers and the price premium is way less than what is in Ferguson's study. Also, the study talks about how much value the peeler can generate with the logs while Ferguson talked about the revenue for growers. He reported a per tree value of NZ$157/stem for average *P. radiata* trees at age 31. The average piece size he used for *P. radiata* is 1.7m^3/stem while the tree data in this study only 1.3m^3/stem. What is interesting is that, by applying a 30% costs ratio (log costs as percentage of total product value), and rebasing the volume to Ferguson's average stem volume, the age 30 *P. radiata* scenario in the study reports similar stumpage value as Ferguson's which is NZ$168/stem. The fact that similar value was obtained in estimating *P. radiata* value with completely different pathways supports the statement of the study could provide accurate result of practical value for the forestry industry.

Supporting growers with the results

Table 5: NZ$/m^3 stumpage value at age 15 required for 8% IRR (Internal Rate of Return) with/without 1BT (1 Billion Tree) Grant on high/low productivity sites. (Millen et al., 2019)

	With 1BT		Without 1BT	
	High productivity site	Low productivity site	High productivity site	Low productivity site
NZ$/m3	13.9	42.2	26.7	81

By applying a 30% log costs over product value ratio to represent the growers log price, the base case scenario presented in Table 4 indicates a per stumpage value of NZ$49/m^3 at DBH 29.6cm (age 15 on Craven Road). The reported stumpage value exceeds any required value in Table 5 except for the one for low productivity site without 1BT Grant. This is to say, with the base case per tree acquired in this study, growing *E. bosistoana* can exceed 8% IRR which suggests planting the species is economically feasible to target 15-year rotation (29.6cm DBH). The only non-feasible site is one that is already forest (cannot claim 1 BT Grant) and with low productivity. However, by producing high value posts and reach the per tree value of that scenario, the stumpage value can exceed the NZ$81/m^3 requirement and makes it feasible to plant *E. bosistoana* trees on that type of land.

Supporting breeders with the results

Based on the results of the study, it is observed that breeding for less growth stress to achieve higher conversion ratio gains more than breeding for higher stiffness which produces higher quality veneers. By increasing the conversion ratio from 0.25 to 0.7, the per tree value at DBH 29.6cm increases for NZ$60/tree while having the pith to bark MoE profile increased from 10.7-15.7GPa to 9-21GPa o 21 only increases the per tree value for NZ$2/tree (under current price premium). What's more, the cost required to increase the stiffness can be as much as increasing the conversion ratio from 0.25 to 0.7 which suggests targeting the growth strain trait is a much better choice. Furthermore, a strong negative correlation (0.68) was observed for the growth strain and stiffness (Davis, 2017), and increasing one of them will causes decrease of the other property. So, it is obviously better to reduce growth strain as the breeding gain is more sensitive to this trait. The result might vary if the market perform differently and a significant price premium are observed.

Future analysis

The model is a viable tool and can be adjusted to use in future studies. One of the biggest obstacles of this study is that there is currently no market of *E. bosistoana* trees nor high stiffness veneer market. The absent of key data makes the study much more difficult. However, as NZDFI expected more than 100,000 hectares of *Eucalyptus* forests to be planted in the next decade (Millen, 2019), the future study of the topic should be easier with the available information.

Conclusion

The study used a model to simulate the value of peeling *E. bosistoana* for veneers and posts It also stressed the most important variables to the value can be realized. Although there are limitations associated with the method, the model and the input variables, improvement can be made for future studies based on the experience of the study.

According to the value extracted from literature, a table of the value range of input variables was summarized which indicates that *E. bosistoana* trees are variable in multiple different properties. A base input scenario for *E. bosistoana* and *P. radiata* each were made with 0.7 conversion ratio, 82mm peeler core and the same tree shape, size. The difference considered in the study between *P. radiata* and *E. bosistoana* is the MoE profile, shrinkage and the possibility of having a smaller corewood or make durable posts from peeler core as a byproduct. Although *P. radiata* produces the majority of the veneer of F07 grade and almost no veneer higher than F13, and *E. bosistoana* produces almost no veneer of lower than grade F13, the modelled *P. radiata* value is lower than *E. bosistoana* at a small DBH and exceed the value of *E. bosistoana* at DBH 33.9cm, NZ$159/tree (age 18 on Craven Road). This is because the base pricing data assumes no premium of grades above F13 to be conservative in estimating value as there is currently no market for those veneers. When the trees reached the maximum DBH tested in the study, a value difference of NZ$17/tree is reported when the *E. bosistoana* tree is NZ$417/tree. It was also noticed that, by having a price premium for higher grade veneers, having a small peeler core (of 30mm) using a spindle-less lathe or make the corewood into posts, the value of *E. bosistoana* exceeds *P. radiata* regardless of tree size.

The most important variables that affect the per tree value of *E. bosistoana* are conversion ratio, veneer prices and post regimes. Peeling machinery (core size) is an important factor when the trees are small, however it gets less sensitive later age for the proportion of the posts to total tree volume keeps decreasing. By decreasing the conversion ratio from 0.7 to 0.25, the value of a tree decreases from NZ$102 to NZ$41 at DBH 29.6cm which makes it the most important factor of all.

The MoE is a less important variable even with an estimated price premium for stiffer veneer grades. The effect of MoE was tested with the estimated price premium (fitted line), and less than 2% difference (NZ$2) in per tree value were found by changing the MoE profile from 9-21GPa (*E. bosistoana*) to 10.7-15.7GPa (*E. nitens*) at DBH 29.6cm. However, the market is unpredictable, there can be a price premium if the market existed. So, it is possible for the MoE profile to be more important than what is suggested by this study.

Based on the result, it is found that making the core as naturally durable posts (even the cheapest one of NZ$368/m^3) makes a tree more valuable than having a very small core and produce more veneers. This is because when it is really close to the pith, the MoE is low and the veneer value are low (NZ$406/m^3) for the poor stiffness. Although, even at a low grade, the veneer price is higher than the price of the cheapest post. The determining factor is that the veneers need to apply with a yield factor while the yield of the posts are 100%. This is because the yield has already been considered and reflected by the price.

Overall, the study supports the growers in deciding if planting *E. bosistoana* is fanatically viable. Based on the economic study conducted by NZDFI and result of this study, *E. bosistoana* is economically feasible to be planted in most sites at an IRR of 8%. The study also allows peelers to apply their own cost models on top of the veneer values and estimate if processing *E. bosistoana* is financially viable.

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